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TECHNICAL NOTE
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A RESTRAINT SYSTEM ENABLING PILOT CONTROL
UNDER MODERATELY HIGH ACCELERATION IN
A VARIED ACCELERATION FIELD

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A RESTRAINT SYSTEM ENABLING PILOT CONTROL UNDER MODERATELY HIGH ACCELERATION IN A VARIED ACCELERATION FIELD

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SUMMARY

A restraint system is described which was used in a joint centrifuge program by the Ames Research Center of the National Aeronautics and Space Administration and the Aviation Medical Acceleration Laboratory of the Naval Air Development Center. The program was designed to study the ability of a pilot in a forward-facing position to control an entry vehicle which employed lift. The pilot was required to carry out a relatively complex tracking problem on a flight simulator which involved the centrifuge operated as a closed loop system. Dynamics typical of an entry vehicle were used and the pilot was subjected to varied acceleration-time profiles with relatively high accelerations, up to 7g, from various directions for approximately 2 to 5 minutes duration. In order to conduct these tests, it was necessary to design a special restraint system. This system combined the use of a modified NASA posterior mold or couch with an anterior restraint made from nylon straps and nylon netting. A special support for the head and face was also incorporated in the restraint system. The use of this restraint system permitted a thorough study of some of the control problems of entry vehicles.

INTRODUCTION

In the design of manned space vehicles that employ lift to minimize the effects of aerodynamic heating and those of deceleration upon entry into the atmosphere, a choice must be made as to the position of the pilot with respect to the vehicle direction of motion. Previous investigation of acceleration tolerance as described in reference 1 has indicated that man can withstand deceleration of a vehicle of the required magnitude if he is placed in a position so that the acceleration vector is applied, for the most part, in a direction transverse to the spinal axis of the body. Consideration of the aerodynamic heating and deceleration problems indicated that a lifting vehicle was of interest and that it would be desirable to place the pilot in a forward-facing position. In such a position, he would be subjected to acceleration forces applied along the spinal axis of the body, transversely to the spinal axis of the body, and along an intermediate vector.

Of greater interest than mere tolerance to such accelerations is the ability of the pilot to perform meaningful tasks while exposed to these stresses. With this latter factor in mind a joint program was established by the NASA, Ames Research Center and the NADC, Aviation Medical Acceleration Laboratory, Johnsville, Pennsylvania. In order to carry out such a study it was necessary to design a restraint system which would enable the pilot to control an entry vehicle while actually immersed in a wide variety of acceleration-time profiles.

In the study reported in reference 2, it was demonstrated that an integrated helmet and restraint suit made it possible for a human to attain certain tolerance levels to various accelerations. It was determined, however, that because at high sustained acceleration the suit was inherently uncomfortable, it would not be satisfactory for our purposes. The NASA, Flight Research Center program described in reference 3, conducted earlier at the Aviation Acceleration Laboratory, employed a modified NASA couch as shown in figure 1, an earlier version of which is described in reference 4. This couch, if further modified, appeared adequate for use in this investigation. Although no requirements were established for an anterior restraint in the FRC program, a restraint garment was deemed advisable for emergency use in the event that accelerations not desired or planned were inadvertently introduced. Such a restraint was designed and tested prior to the FRC program, but no evaluation of its effectiveness was made during the program. It was recognized that a similar design, but with certain refinements, would be ideal for the Ames research program.

Previous experience on the AMAL centrifuge during the simulated boost and re-entry study conducted jointly by that Laboratory and the Langley Research Center of the NASA, described in reference 5, had indicated the need for adequate head restraint. Since considerable forward and downward displacement of the head in relation to the spinal axis of the body takes place for backward transverse and headward accelerations, or any combination of the two, it was necessary to design a head restraint which would prevent such displacement.

With these basic requirements in mind and with the background knowledge of existing restraint systems and their adequacy, a restraint system was designed which permitted the evaluation of control systems and vehicle aerodynamic qualities in varied acceleration-time profiles. This report describes the restraint system which was devised for this flight simulator program.

It is desired to acknowledge the aid of Mr. Richard P. Gallant in the fabrication and testing of the anterior restraint harness and the help of Mr. Arthur J. Gentlemann in the design of the buckles for the restraint harness.

EQUIPMENT DESIGN AND FABRICATION

The experimental program planned for this investigation required that the pilot be restrained adequately during a wide variety of accelerations. The proposed test points are illustrated in figure 2. The actual test points deviated from those proposed during the course of the program. As a result, somewhat greater demands were actually placed on the restraint system. A diagram is presented in figure 3, which illustrates the terminology used in describing the various acceleration vectors. For protection against the positive A_X accelerations up to the planned level of 7g for 2 to 3 minutes, it was felt that a further modification of the NASA couch similar to that used in the Flight Research Center boost program, described in reference 3, would be adequate for this portion of the study. Individual molds were made for each pilot which placed him in a sitting position during these studies as seen in figure 4. His upper body and head were held at an angle of 85°-90° relative to the thigh position. The lower legs were approximately 90° to the thigh position. It was necessary to omit the lower end of the leg mold which included the ankles and the feet in order to permit the installation of toe pedals for yaw control. The toe pedals were designed to restrain the feet in the pedal devices, as illustrated in figure 5.

Protection along the other three acceleration axes of negative A_X, positive A_Z, and combined A_X and A_Z was required. It was necessary to fabricate adequate head, torso, and extremity restraints which would hold the individual in his body mold and yet permit him to perform the required tracking task with maximum efficiency.

The head restraint was incorporated in a protective helmet system shown in figure 6. The posterior couch mold was constructed to permit almost the entire back half of the helmet to be fitted into the mold. The helmet was secured into the mold on either side by 1-inch-wide nylon straps which were attached to the helmet. A head bumper, as seen in figure 6, was incorporated in the system as a secondary safety feature. The face pieces were individually molded from plaster cast impressions made of each subject's face. They were designed so that the major portion of the load would be taken over the prominences of the maxillary bones of the face as illustrated in figures 6 and 7. The chin cup was included in this restraint system but as a minor component only since the chin is an unstable support point with poor tolerance to large loadings. During the early phases of the study these two portions of the face restraint were separate entities. However, it was found necessary to unite them by means of two vertical metal check straps in order to prevent separation during acceleration. The face restraint was attached to the helmet by adjustable 1/2-inch-wide nylon straps fitted into a standard Hardman oxygen mask attachment assembly.

The torso was held in the mold by the use of two separate components. The upper half of the torso was supported by a cloth chest plate fabricated of 6-inch-wide nylon straps crossed over the upper portion of the chest at an obtuse angle so as to cause most of the loading to be taken over the upper rib cage, as seen in figure 8. The upper ends were attached to 4-inch-wide nylon straps which extended over the collar bone and shoulder. Another separate component was fabricated for the pelvis, as illustrated in figure 9. This consisted of two slightly crossed 6-inch-wide nylon straps identical with those used for the chest restraint. These were positioned to distribute the loading over the pelvic bones and the upper thighs.

The limb restraints were constructed of nylon netting held in place by 3-inch-wide nylon straps, as seen in figures 5 and 9. These were fitted and positioned so as to restrain each upper arm, thigh, and lower leg. Nylon netting was used to obtain better molding of the restraint to the contour of the limb.

Buckles were used on the anterior restraint system where it was thought their presence would facilitate the application of the restraint system to the pilot. The anterior restraints were extended through the mold by the attachment of 3-inch-wide nylon straps to each of the anterior components. These straps were secured to the strong back which supported the Styrofoam molds by the use of three-bar fasteners secured to the strong back, as shown in figure 10. This permitted attachment and detachment of the straps of the restraint as desired.

Each pilot provided his own standard g suit to increase his tolerance to positive A_z acceleration.

RESULTS AND DISCUSSION

It was found that the restraint system, for the most part, enabled the pilot to perform the control functions and prevented undue discomfort during the various accelerations. However, numerous shortcomings were discovered which if remedied would considerably enhance the performance of the pilot.

While the face restraint was an untried concept, the basic design was found to provide satisfactory support. Modifications were made during its early use in order to improve its function and comfort. Further improvements in its comfort and adjustability are needed. It must be designed so as to cause a minimum distortion of the facial contours in order to avoid the induction of visual difficulties. The experience gained illustrates the need for an integrated face mask which will permit the restraint of the face under high negative A_x acceleration loadings and will incorporate items such as a microphone.

The torso restraint functioned satisfactorily within the limits to which it was used; however, better tailoring of the chest portion would have increased its comfort. Although the pelvic portion was satisfactory, a problem of integration of this portion with the abdominal bladder of the g suit was encountered. The resistance of the pelvic support caused the bladder to be forced into the abdomen, which often resulted in considerable discomfort and difficulty in breathing.

An uncomfortable pressure sensation in the chest and neck encountered during positive A_x accelerations in excess of 5g was felt to be due to body position. This was partially remedied by enlarging the head opening of the mold to permit higher positioning of the head. The studies of reference 1 have shown that, had the mold itself been flexed forward holding the thigh position fixed with respect to the acceleration vector so that the spinal axis was about 65°-70° to the thigh, there would have been less discomfort in the chest. However, this position, as discussed in reference 1, would have decreased the tolerance to the accelerations in the negative A_x and positive A_z directions.

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The leg and foot restraints functioned well; however, the arm restraints were less satisfactory. When negative A_x accelerations were imposed, there was too much fore and aft movement of the forearm and hand relative to the side-arm controller. Further restraint provided by strapping the forearm and the wrist to the forearm support proved to be a moderately successful temporary solution to this problem. The actual position of the hand and wrist will depend upon the type of side-arm controller to be used. It was discovered that the upper arm was positioned too far back in the posterior mold and as a result was not in a comfortable position. The upper arm should be held in a slightly forward position for maximum comfort. The design of the restraint for the left arm depends upon the extent and manner in which this arm and hand are to be used.

As the program progressed, it was found necessary to add additional protection for all extremities during positive A_z and negative A_x accelerations. When these forces are applied, there results a pooling of tissue fluids and blood in the forearms and legs. In order to prevent this pooling, the forearms and legs were wrapped with elastic bandages as is illustrated in figure 11. A better method of preventing this pooling in the legs would be to make the lower portion of the seat or posterior mold adjustable so that the lower leg could always be positioned at right angles to the direction of the acceleration force.

This restraint system was found to be, in general, very satisfactory for this program. It actually exceeded the requirements for which it was designed. The anterior restraint was felt to be somewhat unsatisfactory from a psychological standpoint because it permitted a certain amount of deflection when the slack was taken up at the onset of negative A_x acceleration. This sensation was disturbing to some but not all of the subjects and appeared to decrease as experience was gained on the centrifuge. In order to be satisfactory, the anterior restraint must be able to create the same sense of security as does the more formidable appearing posterior mold. This sense of security is necessary in order that the pilot be able to devote all his attention to his task without being distracted by the apparent inadequacy of his restraint.

CONCLUDING REMARKS

The described restraint system permitted the successful accomplishment of the program for which it was designed. The wide nylon netting and straps of the anterior restraint provided moderate comfort to the pilot, although positive A_Z and negative A_X accelerations necessitated wrapping the pilot's arms and legs to prevent pain caused by fluid pooling in these extremities. Excessive fore and aft movement of the arms and wrists relative to the side-arm controller during negative A_X accelerations required these limbs to be strapped to the forearm support. The new concept of head and face restraint used in the design was very successful.

The authors feel that certain modifications would significantly improve the system. An adjustable posterior mold or seat would make it possible for the legs and torso to be positioned for the greatest tolerance to the acceleration forces. Movement of the arms relative to the side-arm controller should be restricted, but in a manner which would permit their functional use. At the onset of $-A_X$ acceleration, the anterior straps permit a certain amount of forward body movement. This movement is psychologically unsatisfactory to the pilot and should be reduced to a minimum. An improvement in the integration of the body restraint elements with those for g protection is also needed.

The restraint system permitted the establishment of meaningful time versus acceleration tolerance levels associated with the pilot control of an entry-type vehicle. These tolerance-level results are to be included in a separate report.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Feb. 17, 1960

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Figure 1.- Modified NASA couch used in the Flight Research Center boost program.

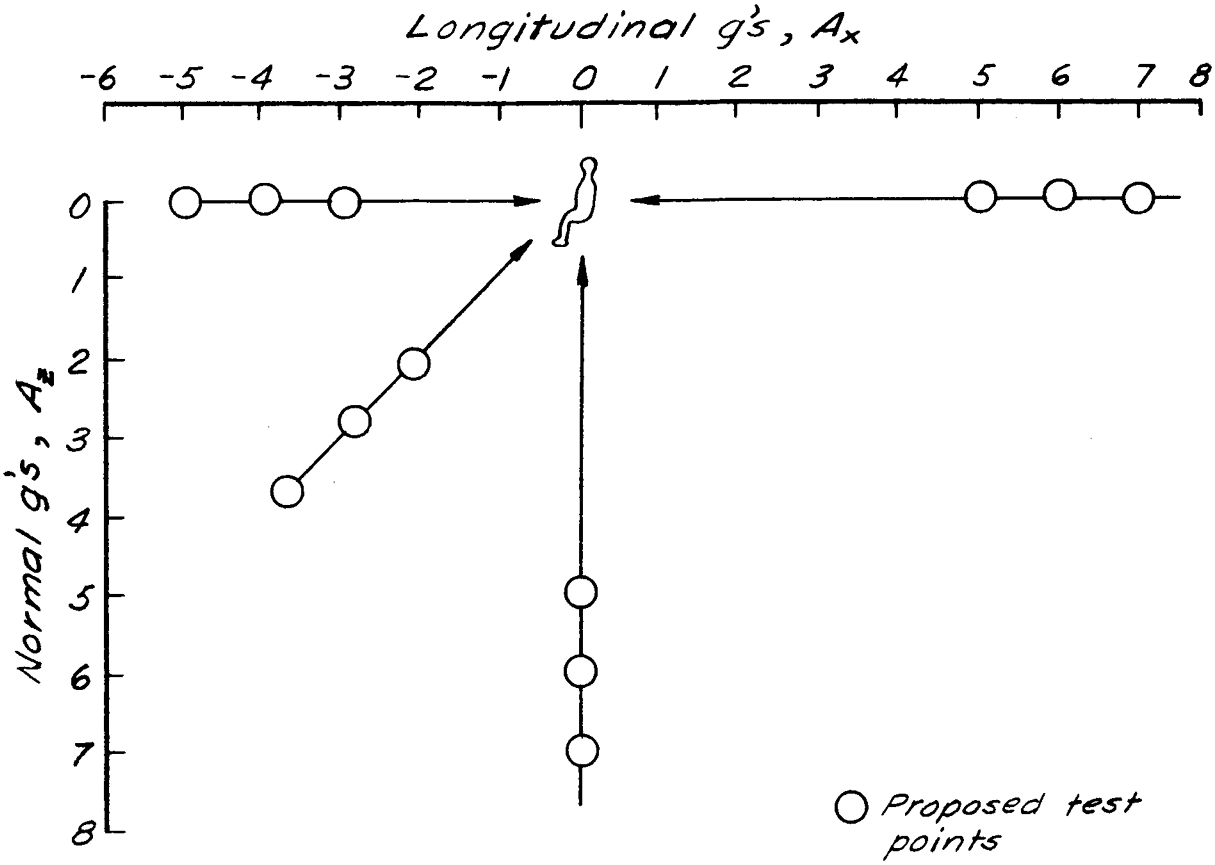

Figure 2.- Proposed test points and acceleration vectors.

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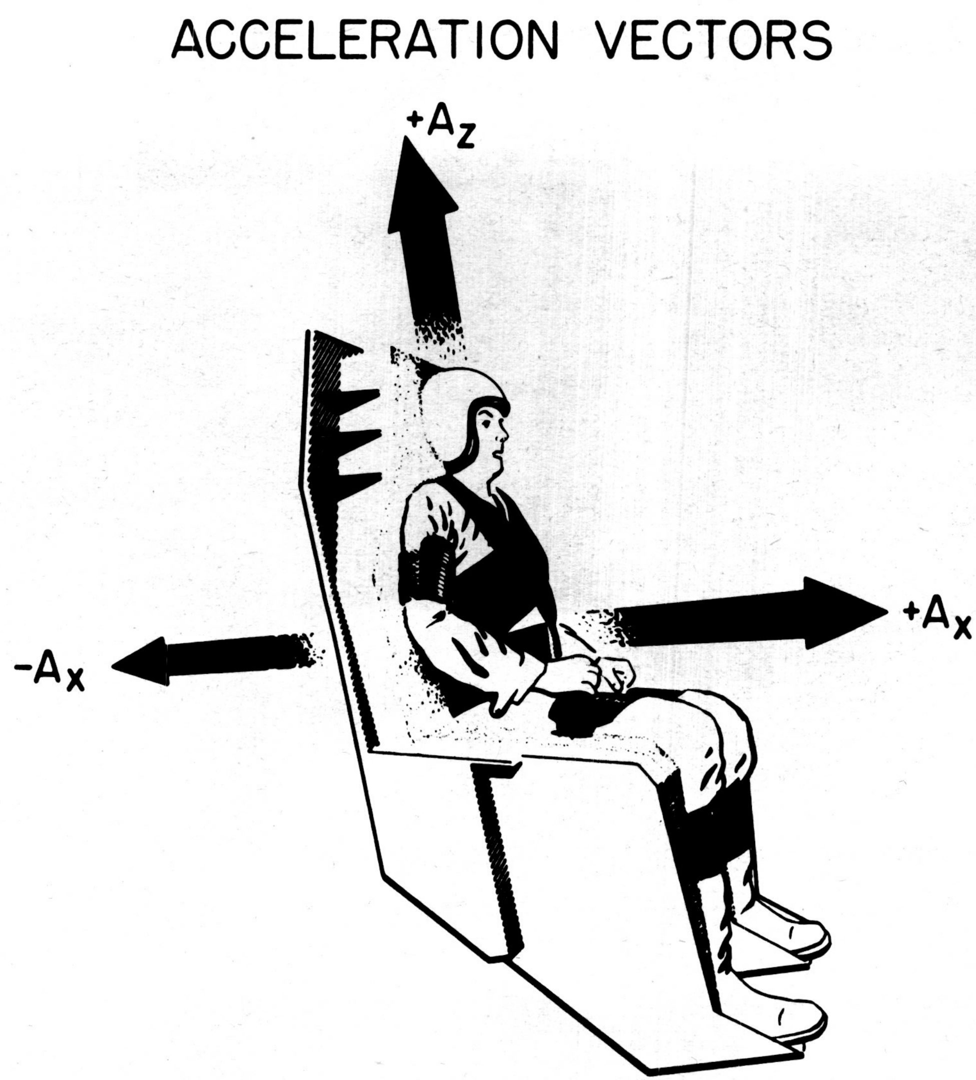

Figure 3.- Definition of acceleration vector convention used in present report.

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Figure 4.- NASA Ames Research Center modification of NASA Couch.

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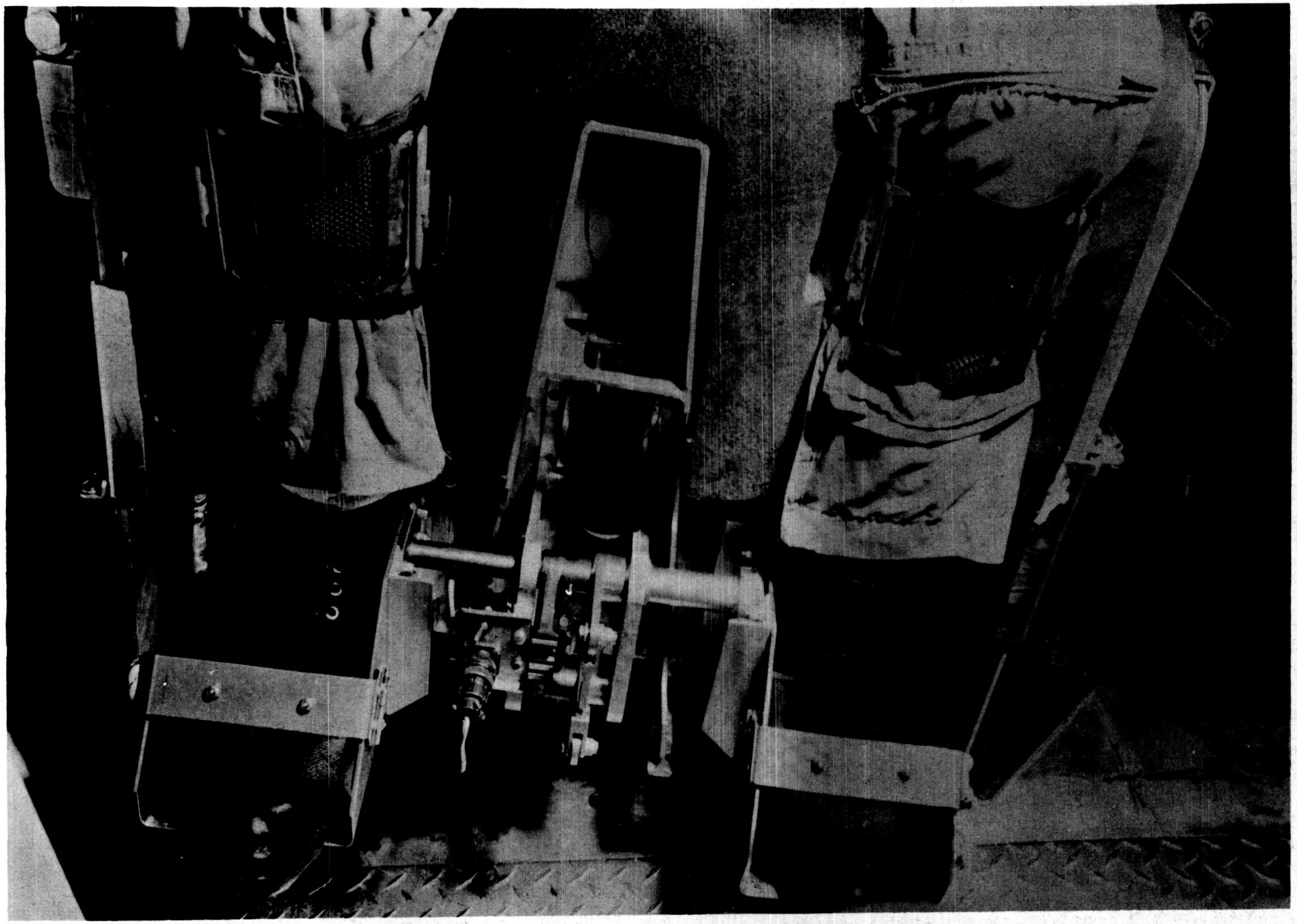

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Figure 5.- Toe pedal devices with foot and lower leg restraint.

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Figure 6.- Protective helmet and head restraint system.

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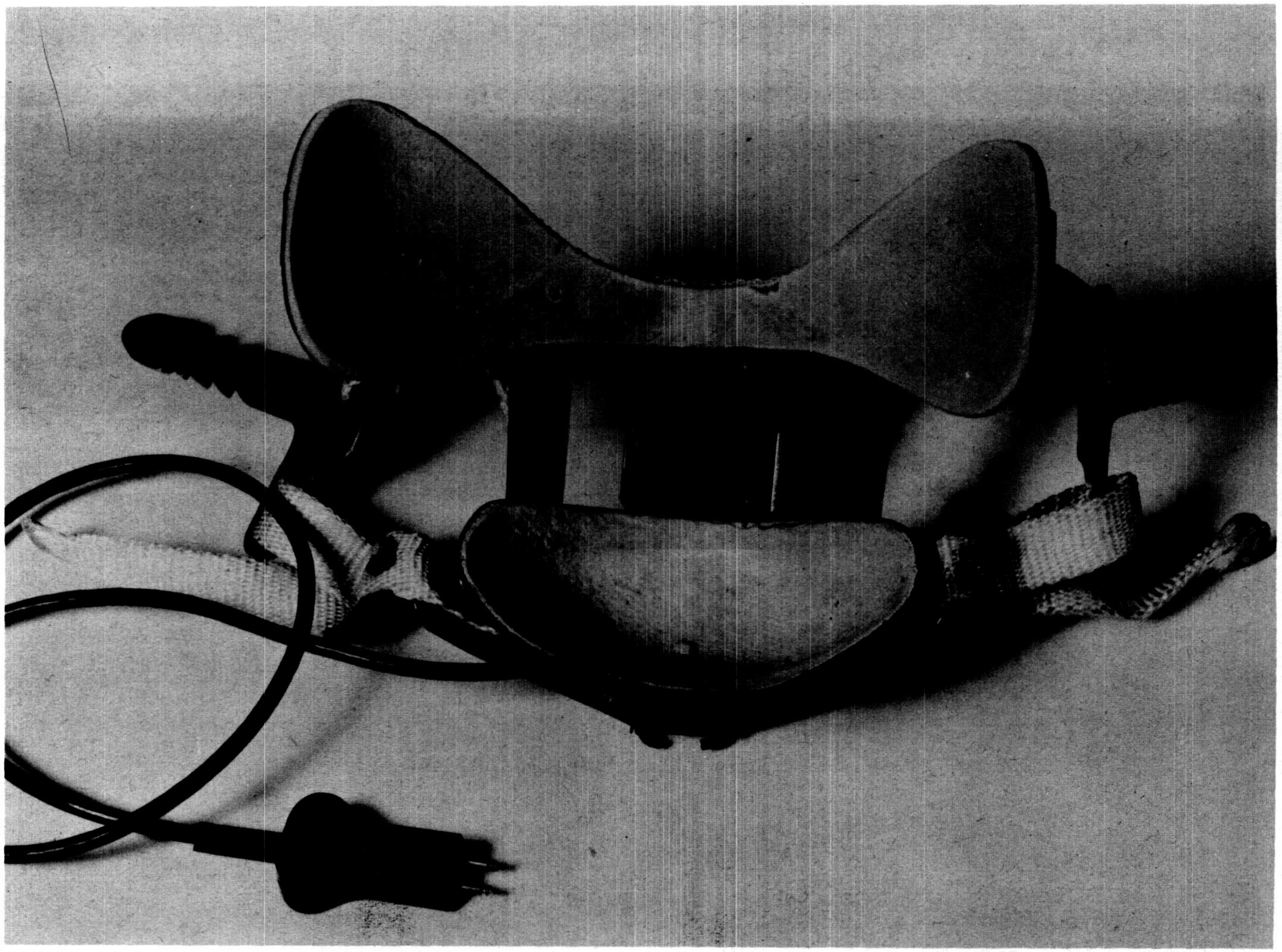

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Figure 7.- Head restraint system showing cheek mold and chin cup.

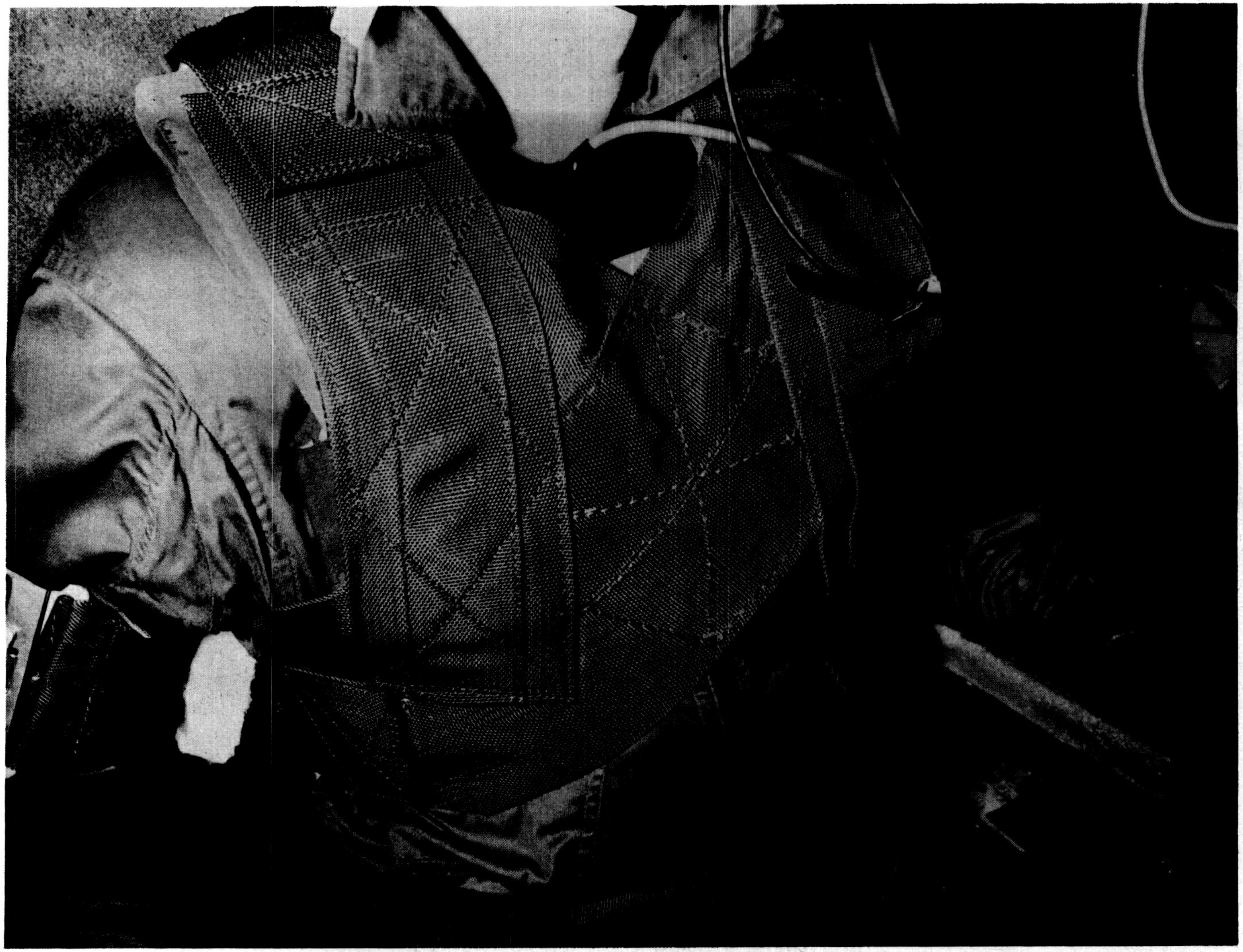

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Figure 8.- Chest and shoulder restraint system.

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Figure 9.- General view of restraint system showing pelvic strap.

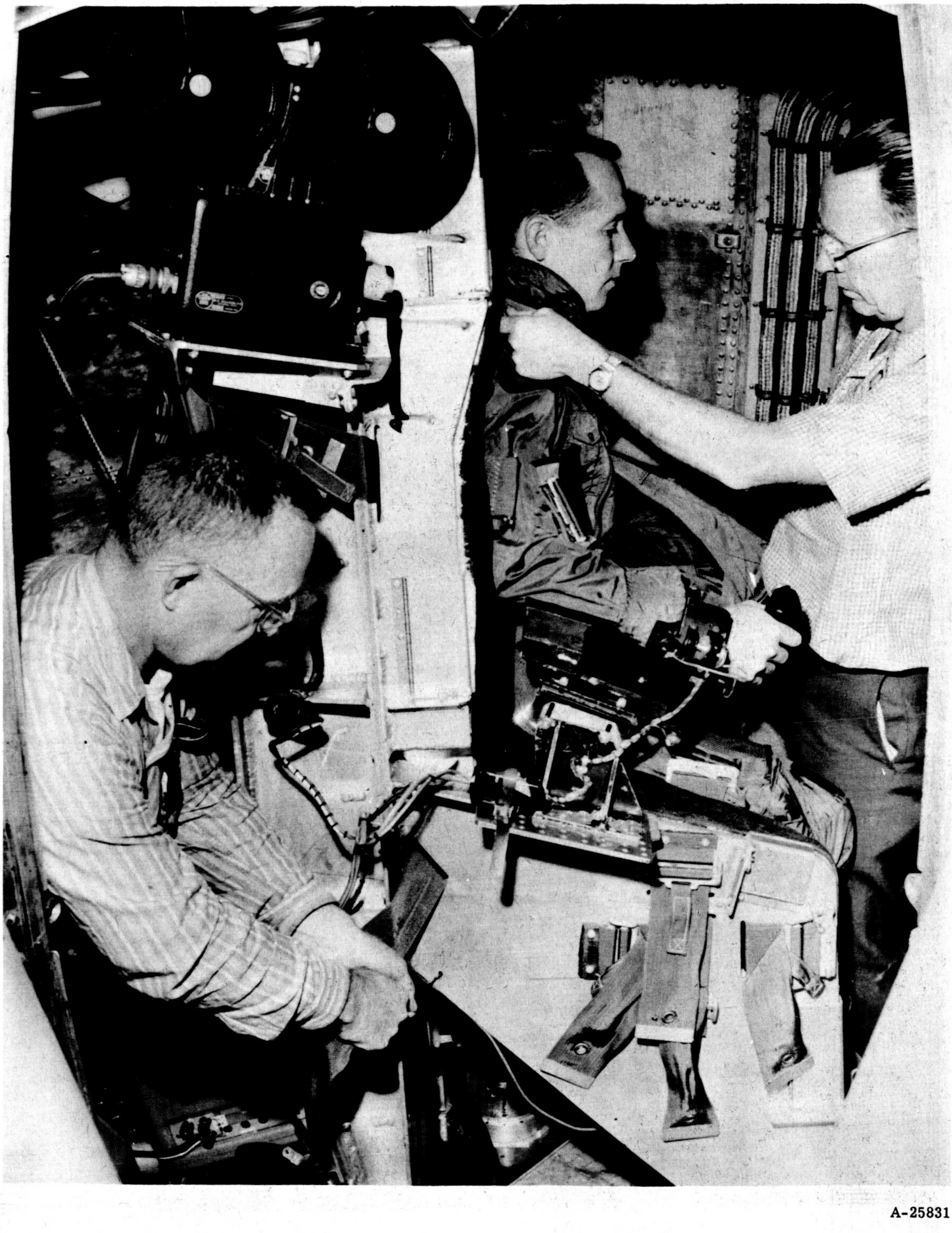

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Figure 10.- Strap and buckle system for attachment and detachment of restraint system.

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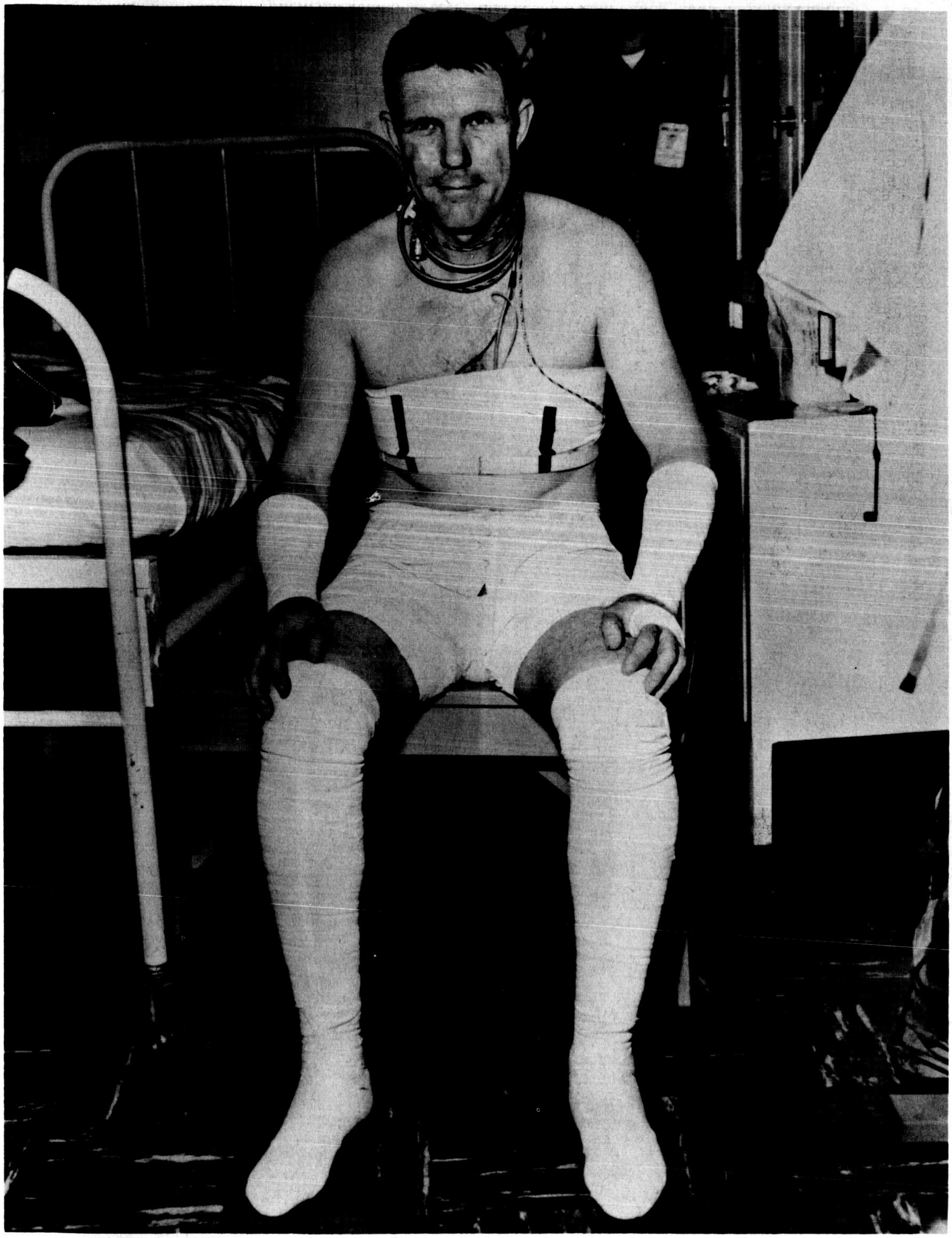

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Figure 11.- Leg and arm wrapping using Ace Bandages.